HANDBOOK OF IMAGING MATERIALS

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Preface

The field of imaging technology has undergone massive changes over the past
fifty years, from the 1940s, when photography served the entire gamut of
reprographic applications, to its narrower focus in the imaging industry today. A
half-century ago, silver halide-based papers and films performed every task from
image capture to document copying.

Diazo processes took on special importance during the war years in the 1940s,
growing rapidly in the 1950s to become the predominant method for engineering
drawing reproduction. Electrophotography grabbed the spotlight in the late
1950s and in the 1960s, when it revolutionized office procedures by increasing
worker productivity through automation. Exploitation of this technology con-
tinues apace in facsimile, in desktop publishing, and in other areas of business
communication.

Today, silver halide emulsion is still the primary image-capture medium for
visible light, infrared, and x-ray photography. Amateur photographers, carrying
some 250 million 35mm cameras worldwide, depend upon this technology. In
the United States alone, the retail photofinishing market reported revenues of
$5.34 billion in 1989, based on almost 15 billion exposures on silver film.

Although it is now a commercial reality, the digital, electronic camera is not
expected to equal the number of photographs taken on silver film until the turn of
the century, when an estimated 23 billion exposures will be made in this country.
While silver photography continues to hold on to the most demanding

its original condition. The toner is swept off the photoreceptor with either a brush of furlike material, a brush of xerographic carrier beads electrically biased to remove toner, or a conformable rubber blade.

In the erase step, the photoreceptor charge is reduced to zero by exposing it to a lamp, which causes the entire width of the photoreceptor to conduct electricity. This erases any remnants of the latent image.

The entire process is then repeated as the photoreceptor drum or belt returns to its starting point.

The steps that are most important to dry toner design are the development and fusing steps. The latter to a large extent determines the polymers that can be used in toner fabrication, since the toner should melt in the fuser and adhere to the paper without contaminating the fuser itself. Similarly, cold pressure fix has its special requirements for toner design (Bhateja and Gilbert, 1986).

Once a toner polymer has been selected and developed, most of the work of toner design goes into assuring that all the toner particles have the proper charge level to give sufficient development without background. This charge level will vary with the machine design.

In addition to these primary considerations, the effects of the toner design on the other steps in the process should be considered. The bulk of the toner should leave the photoreceptor during the transfer step; any remaining toner is typically removed during cleaning. Any microscopic toner constituents that are not removed by the cleaner should not degrade the charging properties of the photoreceptor because this would affect the charging, exposure, and erase steps.

4.1.3 Two-Component and Single-Component Developers

There are two primary methods of charging the dry ink and presenting it to the charge pattern on the photoreceptor to develop the latent image. The first, two-component development, was universally used in the early commercial applications of xerography. The charge is generated on the toner particles by mixing them with much larger beads chosen so that there is sufficient difference in the electrical nature of the toner and carrier materials to generate a charge of the desired magnitude on the toner. The mixture is then brought in contact with the latent image on the photoreceptor. A combination of impact and electrostatic forces removes the toner particles from the carrier beads, and the fields produced by the latent image attach them to the photoreceptor (Schein, 1988).

The earliest machines, such as the Xerox 914, used nonmagnetic carrier beads and poured the developer over the latent image to bring the toner into contact. This was called cascade development (Walkup, 1952; Wise, 1952).

Modern designs almost invariably have magnetic carrier beads and use magnets to control the flow of the developer and bring it into contact with the image. Since the magnetic fields in the contact zone with the latent image are typically designed to form a brush of carrier beads, this form of development is called

magnetic brush development (Young, 1957a,b; Giaimo, 1957). Figures 4.2 and 4.3, respectively, show a typical two-component developer housing and a strand of the magnetic brush between the developer roll and the photoreceptor. Electrostatic forces drive the toner to image on the photoreceptor, while magnetic forces hold the carrier beads on the roll. Section 4.4 discusses toner properties for this application in more detail.

The use of carrier beads is not essential to xerography, although most of the early work and the associated patent literature concerned carrier-based developers. By avoiding the use of carriers, one may have a better opportunity to create one's own proprietary developer technology. As a result, the possibility of charging toner and bringing it into contact with the latent image without using carrier has been investigated by many companies, and several have introduced successful products incorporating what is called single-component technology. A typical housing utilizing this technology is shown in Figure 4.4 (Takahashi et al., 1982). Section 4.5 discusses toner designs targeted for this type of application.

At the present both technologies have an important role in the marketplace. While the same toner technologies can be used for both types of application, the details of the toner design may be significantly different.

4.2 TONER COMPONENTS

Dry xerographic toners consist of a colorant in a binder resin. Beyond these essential ingredients, a particular toner design may contain charge control addi-
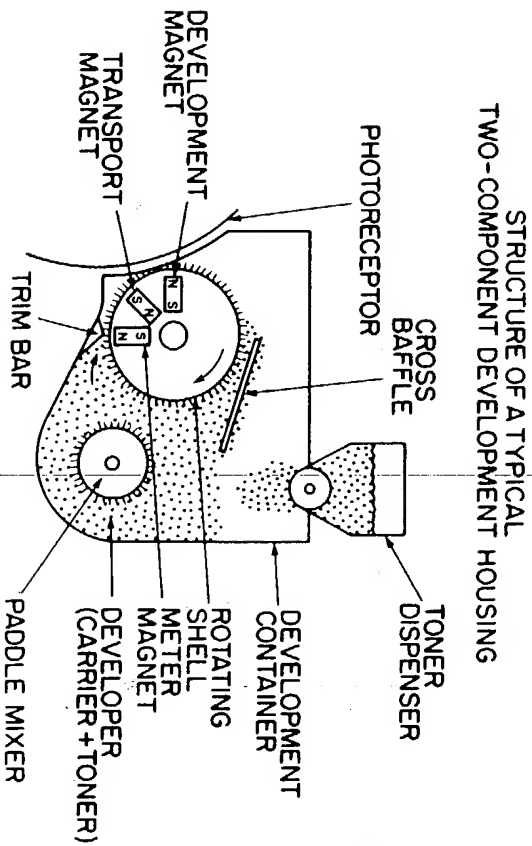
Figure 4.2 Structure of a typical two-component development housing. (From Gruber et al., 1989.)

STRUCTURE OF A TYPICAL
TWO-COMPONENT DEVELOPMENT HOUSING

PHOTORECEPTOR

CROSS
BAFFLE

TONER
DISPENSER

DEVELOPMENT
CONTAINER

ROTATING
SHELL

METER
MAGNET

DEVELOPER
(CARRIER+TONER)

PADDLE MIXER

TRIM BAR

TRANSPORT
MAGNET

DEVELOPMENT
MAGNET

PHOTO-RECEPTOR

ELECTROSTATIC FORCE

MAGNETIC FORCE

CHARGED MAGNETIC TONER

CARRIER BEAD

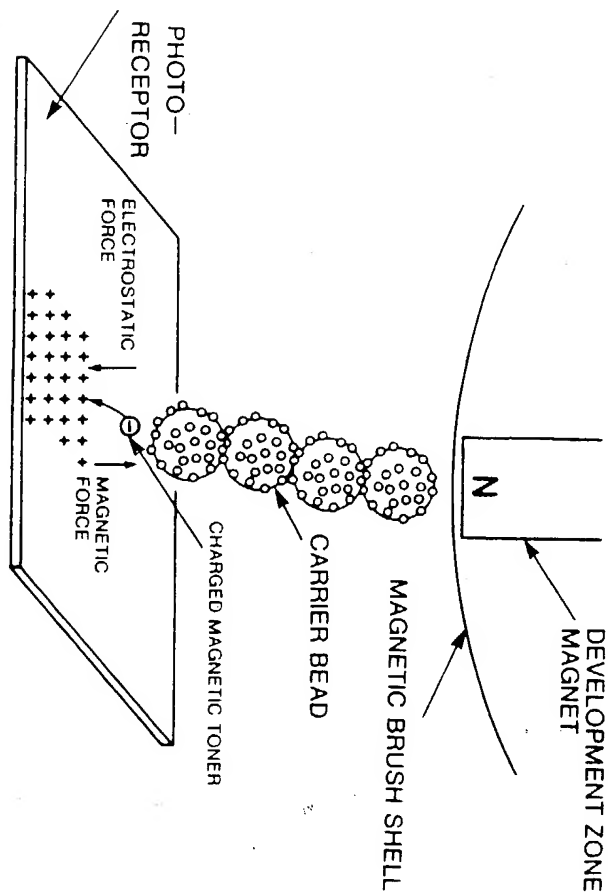**MAGNETIC BRUSH SHELL**

DEVELOPMENT ZONE MAGNET

N

Figure 4.3 Schematic development, indicating direction of electrostatic and magnetic force on toner above an image. (From Scharfe et al., 1989.)
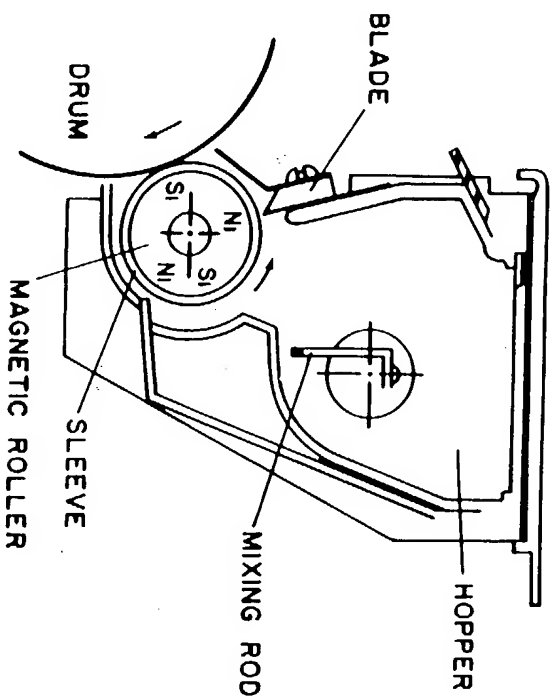
BLADE

DRUM

MAGNETIC ROLLER

SLEEVE

MIXING ROD

HOPPER

Figure 4.4 Single-component development unit. (From Takahashi et al., 1982.)

tives to control the charge level, surface additives to control flow and cleaning properties, magnetic additives to aid in toner control, and waxes to promote toner release from the fuser roll. These components are introduced in the subsections that follow and are treated in more detail when the toner function they affect is discussed.

4.2.1 Resin

Several different families of resins have found frequent application in xerography depending on the fixing technique selected (Table 4.1). The role of the resin in a toner is to bind the pigment to the paper or transparency material to form a permanent image. This is typically done by selecting a polymer that will melt at a reasonable temperature when heat is applied in any of a number of ways or one that can be forced into the paper fibers at high pressure without additional heat.

The materials for the last application are typically lower molecular weight polypropylenes, polyethylenes, ethylene-vinyl acetate copolymers, and mixtures of these materials. These cold pressure fix materials have the advantage of requiring low power in operation and no standby power (Bhateja and Gilbert, 1985a,b, 1986). They commonly have the disadvantage of producing high gloss images that can be easily damaged by rubbing. However, they are perfectly acceptable for some applications, most notably computer printing (Rumsey and Bennewitz, 1986).

In other applications, a continuous radiant source of heat such as a quartz lamp or heated coil is used to melt the toner into the paper fibers. The viscosity of the toner usually reaches quite low melt viscosities in flowing into the paper, but the time allowed for heating can be up to 500 ms. Here polyesters and epoxies are often used. In this application the molecular weight of these materials ranges from 5000 to 50,000 and the glass transition temperature from 50 to 60°C (Palermiti and Chatterji, 1971).

In flash fusing, the toner is melted into the paper by a very short high intensity flash of light lasting less than 5 ms. Toner temperatures typically exceed 200°C in attaining the low viscosities required, and the thermal decomposition of the toner polymer is a significant problem. Styrene copolymers, epoxies, and copolycarbonates have all been used (Gruber et al., 1982; Narusawa et al., 1985).

The great majority of copier designs use roll fusers for fixing the image (Kuo, 1984; Prime, 1983; Lee, 1975). The paper with the unfused toner passes through a nip formed by a heated roll and a backup roll forced against the heated roll at fairly high pressures. This combination of temperature and pressure gives the best overall performance for most applications. Styrene copolymers such as styrene acrylates, methacrylates, and butadienes are used. Molecular weights range from 30,000 to 100,000, and glass transition temperatures range from 50

Table 4.1 Common Toner Polymers

Polymer name or class	Chemical structure	Morphology	Melt properties (*C)	Molecular weight range, $\times 10^{-3}$	Application
Polystyrene-n-butyl methacrylate[a]	$(CH_2—CH)_{65}—(CH_2—\overset{\displaystyle CH_3}{\underset{\displaystyle COOC_4H_9}{C}})_{35}$	Amorphous	$T_g50–60$	50–60	Roll and flash fusing
Polystyrene-n-butyl acrylate[a]	$(CH_2—CH)_{70}—(CH_2—\overset{\displaystyle H}{\underset{\displaystyle COOC_4H_9}{C}})_{30}$	Amorphous	$T_g50–60$	50–60	Roll and flash fusing
Polyethylene	$(CH_2—CH_2)_n$	Crystalline	$T_m86–130$	0.5–15	Cold pressure and roll fusing
Polypropylene	$(CH_2—\underset{\displaystyle CH_3}{CH_2})_n$	Crystalline	$T_m130–165$	3–15	Cold pressure, roll fusing and release agent[b]
Polyethylene–vinyl acetate[a]	$(CH_2CH_2)_m—(CH_2—\underset{\displaystyle OCOCH_3}{CH})_a$	Amorphous		>10	Cold pressure fusing
Polyester	$(O—CH—CH_2O—\bigcirc—C—\bigcirc—OCH_2CH)_m$ with CH_3 groups; $(O—C—CH=CH—C)_n$ with O double bonds	Amorphous	$T_g52–54$	8–10	Radiant fusing
Epoxy	$(O—\bigcirc—\overset{\displaystyle CH_3}{\underset{\displaystyle CH_3}{C}}—\bigcirc—O—CH_2—\overset{\displaystyle OH}{CH}—CH_2)_n$	Amorphous	$T_g \sim 60–100$	1–10	Roll and flash fusing

[a]Monomer ratio expressed in weight percent.
[b]Added to provide release between fuser roll and toner surface.
(From Gruber et al., 1989.)

to 65°C (Nelson, 1984). Where lower melting temperatures are desired, polyester resins have been used (Fukumoto et al., 1985).

The above-named polymers can be specially modified for a particular application by incorporating monomers or side chains to accomplish such functions as charge level modification (Gibson, 1984). However, the primary role of the polymer resin is to fix the image, and polymer designs are developed with their fusing characteristics as the primary consideration.

Toners are typically manufactured by the attrition of the blend of the ingredients. Here the ease with which the polymer breaks up has a very significant influence on the rate at which one can produce toner. At the same time, the toner should not break up when subjected to the stresses within the developer housing (Ahuja, 1976). These mechanical characteristics are another essential consideration in polymer design. Since usually 90% or more of the toner is polymer, its cost is very important in determining the cost of the final product.

4.2.2 Colorants

The most common colorant for xerographic toners is carbon black (Julien, 1982). Most manufacturers offer a range of blacks that differ in such properties as tinting strength and acidity. Important properties of carbon blacks for xerographic applications are their dispersibility in the resin in hot melt mixing and their tendency to charge either positive or negative. Carbon blacks are usually used in toner at a 5 to 15% loading.

Besides carbon black there are several other materials that can be used to make black toners. Magnetite is often used in toners to allow for magnetic control of the toner. The substance is typically black and is seldom used as a pigment per se, but often the loadings for magnetic properties are sufficiently high that additional pigment is not necessary.

Also, some charge control additives such as nigrosine are good black pigments, and their use in a toner can lead to the reduction or elimination of the carbon black.

Pigments other than black are increasingly playing a role in xerography in two applications. The first is a color to be used in addition to black when there is a desire to highlight certain information. Typical colors used for this application are red, blue, green, and brown, made from either a single pigment or a blend of pigments.

The other major application is in the creation of full color documents. Here the subtractive set of pigments, cyan, magenta, and yellow, is used. These pigments are typically chosen for colorimetric properties such as spectral purity and their ability to generate as broad a gamut of colors as possible when blended together. To give permanence to the color image, a degree of lightfastness is useful. This typically means that pigments are more useful than dyes. Usually

organic pigments are used. Copper phthalocyanines are often used for cyans and blues, azo pigments for yellows, and quinacridones or rhodamines for magentas and reds (Macholdt and Sieber, 1988a).

4.2.3 Charge Control Additives

Charge control additives are typically added to a toner when the pigment (chosen for its color) blended into the polymer (chosen for its fusing performance) does not give either an adequate charge level or rate of charging. This can happen in both positive and negative charging applications.

For positive applications, one family of charge control additives is the quaternary ammonium salts (Lu, 1981). The quaternary ammonium salts are typically colorless, allowing their use in color applications.

Nigrosine is pigment that is very effective at giving the toner a positive charge (Macholdt and Sieber, 1988a), but it is black, hence unsuitable for most color applications.

For negative applications, acidified carbon blacks have been typically quite successful as charge control agents in addition to their pigment qualities (Julien, 1982). Also the fumed silica surface additives described in the next section assist negative charging (Schein, 1988). In applications calling for additional negative charge control, metal complexes have been found to be effective (Inoue et al., 1985; Birkett and Gregory, 1986).

4.2.4 Surface Additives

Good flow properties are usually desired and often are critical for a toner. This is at times impossible to provide with pigment in a resin base without surface additives. When materials such as fumed silicas are added to the surface of a toner, the flow properties almost always improve dramatically. The use of these materials to impart good flow to powders that would otherwise tend to stick together is by no means limited to xerography (Barby, 1976). The silicas also improve transfer from the photoreceptor to paper by lowering the adhesion of the toner to the photoreceptor (Weigl, 1982) and improve the charge stability of the toner and carrier mixture (Nash and Bickmore, 1988).

For blade cleaning, surfactant materials such as zinc stearate are often blended with the toner to lubricate the blade passing over the photoreceptor (Weigl, 1982). Fumed silicas may be used with the stearate to control the buildup of material on the photoreceptor.

4.2.5 Magnetic Additives

Magnetite is primarily added to toner in single-component applications, where it enables the transport of the toner through the developer housing and against the

latent image under magnetic control (Button and Edberg, 1985). The additives are typically a few tenths of a micrometer in size.

More recently it has been found that even in two-component development, where magnetite is not necessary for developer transport, this material offers advantages in controlling machine dirt (Knapp and Gruber, 1985). Here the typical loadings are about 15 to 20% as opposed to the 60 to 70% necessary for toner transport. Referring back to Figure 4.3, the magnetic field in the development nip tends to hold the toner on the developer roll even if it has very low charge. Without magnetite, low charge toner often gives severe dirt problems.

If sufficient magnetic remanance is present within a toner formulation, the toner can be used for magnetic ink character recognition (MICR), a special xerographic application for check sorting (Gruber et al., 1985a,b). Typically, a grade of magnetite with a high remanence is used at a loading in excess of 20%.

4.2.6 Other Additives

Fuser rolls typically require the use of a release agent such as silicone oil to prevent the adhesion of the toner to the roll during fusing (Seanor, 1978). It simplifies the design of the hardware if this release agent management system can be eliminated. It is possible to do this by incorporating a low molecular weight polyethylene or polypropylene wax into the toner itself (Gruber et al., 1986). This flows very readily at temperatures sufficient for toner fusing and fills the role of the silicone oil. Partial cross-linking of the polymer in the toner is also helpful to prevent adhesion to the fuser roll (Inoue et al., 1985).

4.3 TONER REQUIREMENTS AND CHARACTERIZATION TECHNIQUES

The development of a toner involves the choice of the components described above, starting with the choice of polymer and proceeding through the selection of each component to fit the particular application. Techniques have been developed for each of the requirements to facilitate selection, and these are often unique to the xerographic application.

4.3.1 Rheology

There are three xerographically significant temperatures necessary to characterize a toner for xerography. The most obvious is the temperature at which the image is fixed to the paper. This will vary with the degree of fix required, but for an adequate fix level it is called the minimum fix temperature. Above this is a temperature at which the toner is so fluid that it simply splits apart when the paper leaves the fuser roll, leaving traces of the image on the fuser roll

to contaminate the next sheet. This is called the hot offset temperature. Finally, the toner should not sinter when left on a loading dock or in the machine toner hopper, even at an elevated temperature. The temperature at which significant sintering occurs is called the blocking temperature (Weigl, 1982).

Adequate fix is a subjective judgment and can vary with the application. Measurements of fix level generally involve abrading an image on paper in a controlled way and measuring the amount of toner lost from the paper or the change in the density of the image (Bhateja and Gilbert, 1985a).

The minimum blocking temperature allowable is determined by the highest temperature one expects the toner to see outside the fuser. It is often asked to be about 115°F. To a large extent this is a characteristic of the toner resin. However, it can be modified by the other ingredients of a toner. For example, carbon black can act as a reinforcing agent, raising all the characteristic temperatures including the blocking temperature (Ahuja, 1980c; Fox, 1982). Similarly, surface additives such as fumed silica will typically prevent sintering, hence raise the blocking temperature (Barby, 1976).

Even though additives can modify the results, the primary means for controlling the fusing properties of a toner is through the resin. The lowest possible minimum fix temperature is desirable, since this will typically minimize power consumption and maximize fuser life. For a given minimum fix temperature, the hot offset temperature should be as high as possible to maximize fuser latitude. The latter two temperatures in particular should be measured in the fuser of interest; more general rheological measurements can serve as an aid to polymer design, although they are not sufficient for final approval.

A commonly measured characteristic of a polymer is its glass transition temperature, T_g, where the polymer changes from a hard glass to a rubbery state. This is measured in a differential scanning calorimeter, which looks for the change in heat capacity at the transition. For adequate blocking toners generally should have T_g values above 50°C.

Another relevant characteristic of the polymer is its melt viscosity, that is, its ability to flow at a given temperature. The rate at which this falls at and above T_g determines the temperature above the blocking temperature at which the toner flows into the paper, and the temperature above this at which the toner splits leaving residue on the fuser roll as well as on the paper.

These characteristics can be varied by varying the composition and molecular weight of copolymers. This can be illustrated by examining one of the most common copolymers, styrene–butyl methacrylate. For a random copolymer, the T_g is given by

$$T_g = W_1 T_{g_1} + W_2 T_{g_2} + kW_1W_2$$

where W_1 and W_2 are the weight fractions of constituents 1 and 2 and T_{g_1} and T_{g_2} are the transition temperatures of the homopolymers (Manson and Sperling,

limited number of pigments, the goal is usually to obtain values sufficient for almost any possible application.

However pigment evaluation can only predict the largest gamut possible. The real color gamut a given set of pigments will produce in a particular color copier is also affected by the smoothness of the image formed by the fused toner and the general quality of the image formed by the xerographic system (Nakaya et al., 1986).

4.3.3 Particle Size

Toner particle sizes are generally in the range of about 10 to 20 μm in diameter. Particle sizes significantly larger than this usually produce ragged lines and dots and thus degrade copy quality. As a result, smaller sizes have been found to be superior for color reproduction (Chiba and Inoue, 1988) and for noise reduction in general (Nelson et al., 1982). However, for a given resin the smaller sizes require longer grinding times in manufacturing, hence are more expensive to produce. Also smaller sizes tend to produce more dirt at a given charge-to-mass ratio (hence development efficiency) and to cause more rapid developer degradation (Nash and Bickmore, 1988). These limitations on the practical size of dry toner is one of the attractions of liquid systems (Weigl, 1982).

Even if the average size is reasonable, a broad particle size distribution will introduce significant amounts of the small and large toner particles that cause dirt and copy quality problems. As a result, toner processing strives for the narrowest practical size distribution. This is typically done with well-designed microniza-tion equipment followed by air classification and possibly sieving.

The size distribution is measured by the use of the Coulter counter or similar instrumentation. This places the toner particles in a conducting fluid and exam-ines changes in signal as the particles are passed through an orifice. The instrument is sensitive to the volume of liquid displaced by each toner particle, hence gives an accurate measurement of the volume size distribution of the toner. The distribution can be characterized in various ways, most typically by the geometric (logarithmic) standard deviation, the number fraction of particles below a certain size, and the volume fraction of particles above a certain size.

An optical image analyzer can also be used for toner size analysis if the particles are spread out on a microscope slide. This method looks at the projec-tion of the particles in the object plane and can be used for linear or areal measurements. This method is often used in conjunction with a charge spectro-graph to make simultaneous measurements of toner size and charge as discussed in Section 4.3.4.

Since the electrolytic displacement and optical methods measure the size in quite different ways, there can be a significant displacement between measure-ments from the two techniques, and comparisons should be made using the same method.

4.3.4. Charging

To control the toner particles in the electric field of the photoreceptor, the toner particles are given a well-defined charge. Much of the progress in the creation of clean, crisp copies and prints by means of xerography has come through in-creased control over toner charge distributions. This in turn has been facilitated by increased sophistication in charge characterization methods.

The primary method of characterization of the charge on toner has been the measurement of the charge-to-mass ratio (Schein, 1988). For two-component development this is typically done by putting the developer in a metal cage with screens on each end large enough to allow toner but not carrier beads to escape. The mass of the developer in the cage is determined, and the cage is connected to an electrometer. The toner particles are then blown off, and the charge and mass differences that result are measured. The ratio of these differences gives the charge-to-mass ratio for the toner blown off. This quantity is called the tribo or blowoff tribo for that developer.

The same quantity can be determined for toner on a photoreceptor or single component donor roll by drawing the toner into a chamber connected to an electrometer and weighing the chamber before and after. Because of size selectivity in development, the blowoff tribo measured for toner developed onto a photoreceptor will not necessarily be equal to that for the same toner when still mixed with carrier.

Another method of charge characterization that has become increasingly common in the industry is the charge spectrograph. In one embodiment of this instrument (Lewis et al., 1981a,b; 1983), the toner is drawn into an airflow while simultaneously exposed to a perpendicular electric field. The combination of viscous drag and electrical forces determines where each individual toner particle falls on a collection filter. Rather than the charge-to-mass ratio (q/m) that the previous technique measures, the charge spectrograph measures the charge-to-diameter ratio (q/d). The average charge-to-diameter ratio can be determined by eye from the trace on the filter very quickly, but the instrument also allows the simultaneous determination of the charge-to-diameter ratios and the diameters for all the individual toner particles. For the latter application computer analysis of the collection filters is necessary.

Several other realizations of charge spectra characterization are described in the literature (Kutsuwada et al., 1985; Epping, 1988), and instruments are commercially available from Epping GmbH and Hosokawa Micron.

It is important to realize that charge spectrograph measurements can be significantly different from blowoff tribo measurements. Most theories of toner charging predict that the charge will be proportional to the toner area (Anderson, 1987; Anderson and Bugner, 1988), and this is indeed the general result, although there can be significant deviations (Terris and Jaffe, 1987). This implies that q/d^2 is a constant as the toner size changes, and this in turn leads to

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5

Carrier Materials for Imaging

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5.1 CARRIER DEFINITION AND FUNCTION

Carrier is a general term in xerographic imaging or printing that applies when a two-component developer is used. In such cases the developer is made up of toner and carrier mixed together (Fig. 5.1). The toner is the "ink" that actually makes the mark on the paper.[1] It is generally a low melting polymer compounded with approximately 10% carbon black and ground to a particle size of about 12 μm. The carrier, a powder material from 3 to 50 times larger than the toner, is the subject of this chapter.

Developers range from 1 to 10% toner by weight, and the toner is "carried" by the carrier to the electrostatically charged image on the photosensitive drum in the copier. One of the most important functions of the carrier is to impart a static charge to the toner particles. This is accomplished by the surface contact with the toner during mixing, in the phenomenon known as triboelectrification. This term comes from a combination of Greek words meaning "to charge by rubbing" and is exactly like the old experiment of charging a glass rod enough to pick up small bits of paper by rubbing it against a cat's fur. A common example is the unpleasant experience of being shocked by touching a doorknob or another person after walking on a carpet on a dry day. In the case of xerographic developers the combination of toner and carrier properties must be chosen to obtain the correct amount of electrostatic charge on the toner so that the right amount is attracted to the oppositely charged image area. It is important that the
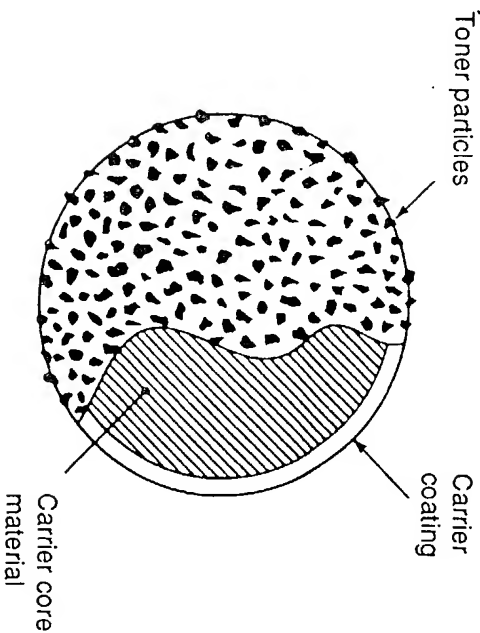
Toner particles

Carrier coating

Carrier core material

Figure 5.1 Cross-sectional view of a coated spherical developer.

toner not be charged too high, so that it cannot be stripped from the carrier, or too low, so that it is not held by the carrier. Low charged toner just floats around the machine, causing dirt, or settles in nonimage areas, causing background on the copy.

5.2 MATERIALS (HISTORICAL)

5.2.1 Xerox Corporation

Any discussion of carrier materials must begin with those used by Xerox Corporation because that is where the whole process started and grew. In the early demonstration of "xerography" by Chester Carlson in 1938, the carrier used was uncoated iron powder, and the image was formed by cascading the developer over the image until enough toner had developed to produce a visible mark or readable character.[2] In the early stages of commercialization of the process, carriers had to be taken from the powders available in the marketplace, and most of the design work was empirical because little was known about the triboelectric charging effect.

In 1950 the company Carlson worked for, then Haloid Corporation, introduced a manually operated offset plate maker called the Model D; the carrier used was washed and screened sand. This carrier was approximately 600 μm in size and was lacquer coated to obtain the desired charging effect. From that beginning, many different powdered materials have been used (see Section

5.2.2), as the industry expanded to many companies and the customer requirements became much more sophisticated. The output copy has progressed from something barely readable to high quality images including solids and halftones, produced at ever-increasing speeds.

The development subsystems have progressed from cascade (Fig. 5.2) to magnetic roll transport (Fig. 5.3) for delivering the developer to the image. The carrier materials design requirements have kept pace so that much, but not all, of the empiricism has moved into the realm of science. As the machines and copy quality have progressed, so have the developer packages and, naturally, the carriers. During the early improvements in machine design there was little carrier development because almost anything would "work," and the demand for copiers and duplicators was high. Any two things rubbed together exchange charge, and the product was consumable and habit forming. The expansion got somewhat ahead of the engineering and science.

The powders that were available for other applications were utilized. Some were specially screened distributions obtained from abrasive powder suppliers. Originally these materials were designed for shot blasting or scarfing applications such as cleaning plastic or metal parts. Others were taken from the powdered metals designed for use in pressing parts by compaction and sintering. Generally copier manufacturers used tailings or fines from these sources rather than developing a process for customized copier powders. As the industry grew, competition and customer awareness of copy quality forced increasingly stringent specifications to be placed on the carriers as well as the toners.
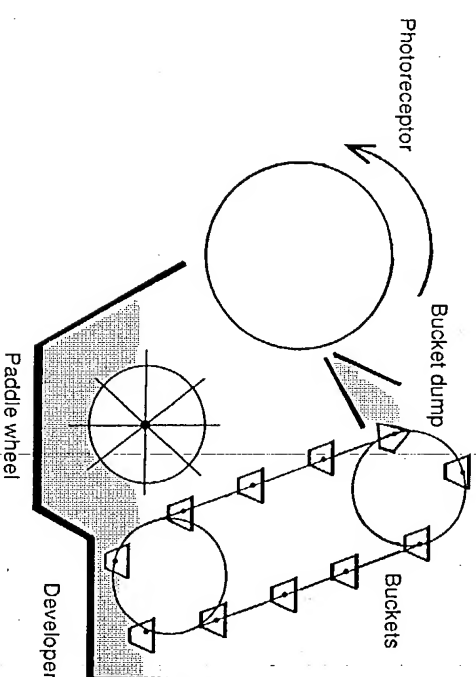
Photoreceptor

Bucket dump

Buckets

Paddle wheel

Developer

Figure 5.2 The cascade development process.